PAPER SURFACE TOPOGRAPHY BY RANGE FROM FOCUS

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Keywords: Microscope, Range, Imaging, Topography, Newsprint

Abstract: The quality of low grade printing paper is largely determined by the physical paper properties. The surface topography is one important factor which has traditionally been measured by pointwise scanning with a mechanical or optical probe. Range camera methods provide a much faster measurement. The "Range from focus" method utilizes the narrow depth of field in a large aperture optical system to obtain range data. A range image is made by collecting a sequence of greyscale images at closely spaced successive focus positions, and then processing the image data to find the optimal focus position for each point in the imaged region. Here, the method is applied to microscopic images of a newsprint paper sample to obtain a topographical map of the paper surface. The resulting range image is dense and quite accurate, and the measurement is fast. There are also numerous possible ways to further improve upon the range image quality, out of which only a few have been tried.

Introduction

In the paper and printing industry, there is an increasing interest for detailed examinations of the topography of the surface of printing paper. Ordinary depth or thickness measurements are performed mechanically or optically by scanning the surface point by point. A much faster way of collecting three-dimensional information about the surface is by means of some kind of range imaging method borrowed from the field of computer vision. This would yield a whole patch of range data in one blow, which would significantly reduce the costs of obtaining a detailed depth map of a large surface. Another benefit with the range imaging approach would be that apart from the range image, exactly the same experimental setup could be used to obtain an ordinary reflectance image of the same patch of the surface, which would make it possible to perform correlation studies between mechanical and optical properties, e.g. for analysing prints.

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The range from focus method

The range from focus method is not by far the most widely used range imaging method in the field of computer vision. The reason for choosing this method for the study was that it requires no special lighting setup nor special imaging hardware. The method is extensively described in [Nay90]. A brief summary is presented below.

In short, the method is based upon a sequence of images, all of the same field of view, but with a sequential change of focus position. This yields a stack of 2D images, a *focus sequence*. See figure 1. A *measure of focus* is then calculated for each point of each of the images. This measure is basically a differential operator. When a part of the image is in focus, the most of the high spatial frequency detail in that part is imaged, and the local energy content of the image has a maximum.

Let $f(x,y)$ denote the greyscale image, where x and y are the spatial coordinates for a point in the image and $f(x,y)$ is the intensity value at that point. For the measure of focus, the ordinary Laplacian operator $L[f(x,y)]$ can be used, where:

$$L = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} \qquad (1)$$

A better measure, however, is the modified operator described in [Nay90]:

$$L_m = \left|\frac{\partial^2}{\partial x^2}\right| + \left|\frac{\partial^2}{\partial y^2}\right| \qquad (2)$$

This modified Laplacian operator has approximately the same characteristics as the ordinary Laplacian, but it also detects 2D "saddle points" where one term of the Laplacian is negative and the other is positive. This situation is also a kind of fine detail in the image, so the modified Laplacian operator was chosen.

The Laplacian type of operator is very sensitive to noise. To reduce the influence of noise, the focus measure images were thresholded so that only values of $L_m[f]$ above a (low) minimum level T were processed, and the images were simultaneously slightly smoothed with a local average filter, giving the final sharpness measure $S(x,y)$:

$$S(x,y) = \sum_{u,v \in \Omega,\ L_m[f(u,v)] > T} L_m[f(u,v)] \qquad (3)$$

where Ω is a neighbourhood around the pixel at (x,y). This procedure was presented in [Nay90], too.

The sharpness measure $S(x,y)$ at corresponding points (x,y) in each of the images can be plotted as a sharpness function $S(x,y,z)$ against the z coordinate, i.e. through the sequence of image planes. One curve is obtained for each pixel in the field of view. The peak position z_{peak} of each curve is detected, and the peak position is taken as the position of the surface at that point.

The surface positions are assigned to pixel values in a *range image* $R(x,y) = z_{peak}(x,y)$. The range image can be visualized as a greyscale image, or as a perspective plot of the surface.

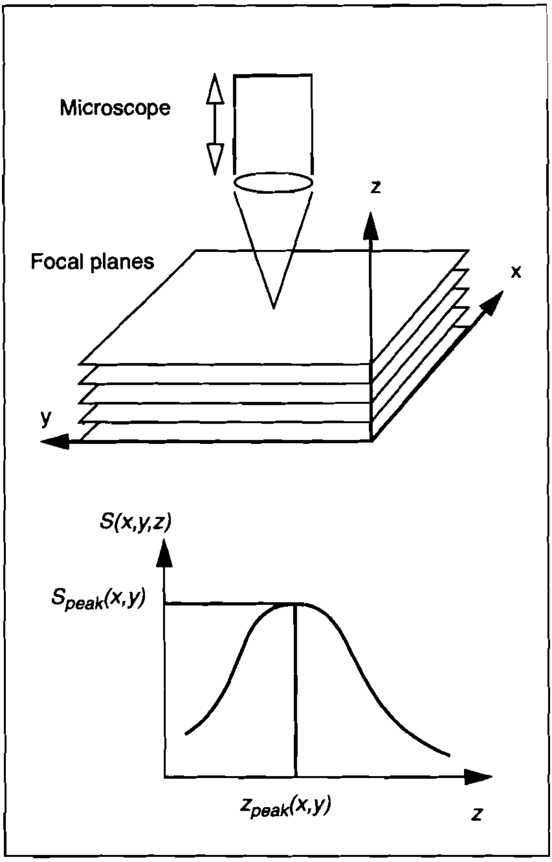

Fig. 1: The principle for range from focus

Range image for a paper surface

To test the applicability of the method, a focus sequence was made from microscopic views of a newsprint paper sample at high magnification. The experimental setup was an ordinary optical microscope with a video camera fitting and a framegrabber to digitize the images. The images were taken with dark-field illumination from above, as this proved to give good contrast for fine detail in the image. The images were digitized to 512×512 pixels 8-bit greyscale. The field of view was approximately 0.2 mm square, and images were taken from 40 focus positions one micrometer apart. The sharpness measure $S(x,y,z)$ was calculated, and the range image $R(x,y)$ was estimated by a simple maximum search through the sequence:

$$R(x, y) = arg\{\max_{z}[S(x, y, z)]\} \qquad (4)$$

The range image obtained in this way was not very accurate. For a surface to be properly detected, it must have some kind of texture to focus upon. Although newsprint paper is fairly rough at high magnification levels, there are parts of the image that have very little detail, and therefore the range image data is uncertain at many points and has quite a few large errors in the form of erroneous "spikes", where the image noise yields a false peak. This range image is shown in Fig. 2. Light areas in the image are closest to the observer, dark areas are farther away.

A simple local averaging operation reduces the errors, but the resolution of the range image is significantly reduced, as can be seen in Fig. 3. Furthermore, the influence of the noise "spikes" is still unacceptably large.

A better way of improving the range image is by looking at another property of the sharpness function, namely the peak height, S_{peak}. If the peak is high, there is strong detail in the image, and the measure should be trusted. If the peak is low, there is little detail in the image, and the measure should not be trusted. Thus, the peak height h_{peak} is a good *measure of confidence* for the range data. If this measure of confidence is evaluated for each pixel in the image, we can make a *confidence image* $C(x,y) = S_{peak}(x,y)$. This can be used to make a straightforward weighted average $W(x,y)$ of the range image:

$$W(x, y) = \frac{\sum_{(\xi, \eta) \in \Omega} R(\xi, \eta)\, C(\xi, \eta)}{\sum_{(\xi, \eta) \in \Omega} C(\xi, \eta)} \qquad (5)$$

Where R is the range image, C is the confidence image and Ω is a neighbourhood around the pixel at (x,y). In this preliminary study, however, this method showed no improvement over the previous one, since the original image quality was quite bad.

The properties of the noise, i.e. more or less isolated erroneous spikes, gave a hint to try methods like median filtering or morphological image enhancements. With a small 5x5 median filter the image was improved a lot with a good preservation of the resolution (Fig. 4). A geometric speckle reduction filter [Cri85] also gave a good result, although chosen somewhat ad hoc (Fig. 5).

Further suggestions

Quite a few ideas for improvement fell outside the scope of this short preliminary study. Some of these are listed below.

The value for z_{peak} was only taken as the integer index for the position of the sharpness maximum. A better accuracy could be obtained by interpolating the peak position, using several data points and assuming the peak has a Gaussian shape, or by fitting a parametric curve to the data for each point. With good quality images to start with, this would be a good approach. However, the data for this preliminary study was quite noisy, so this attempt was not made.

The simple median filter or the despeckle filter are not the best choices for enhancement of the range image. A measure of confidence exists, and should be used. The simple weighted average that failed could be replaced by a more complicated relaxation operation to further propagate range data with high confidence and replace erroneous values, or some kind of adaptive variation of the resolution could be tried, like the one described in [And92], where regions of low confidence are presented with lower resolution than areas of high confidence.

A better sharpness estimation operator could be used. The modified Laplacian is very sensitive to noise, so some attenuation at the highest spatial frequencies could prove useful. This could eliminate the need for the ad hoc threshold to obtain a noise-resistant sharpness measure $S(x,y,z)$.

The field of view is very small. It may be increased by choosing a lower magnification for the images, but then the depth resolution is decreased due to the fact that the depth of field increases with decreasing focal length. Another way would be to translate the sample and make a range image for several adjacent fields of view. This process could be made automatic and should not be all that slow, since the processing of one focus sequence is quite fast.

Conclusion

The range from focus method is applicable to at least newsprint paper surfaces. The range data obtained has a high resolution and the computations are quite simple and fast. With an additional confidence measure for the range data, the influence of noise can be reduced. In this preliminary study, some simple non-linear filtering of the range image data gave a dense and fairly accurate range image with good resolution.

Acknowledgements

This study was financed by a grant from the Swedish National Board of Research. STFI, Stockholm, kindly provided access to their microscope equipment for collecting the test images.

References

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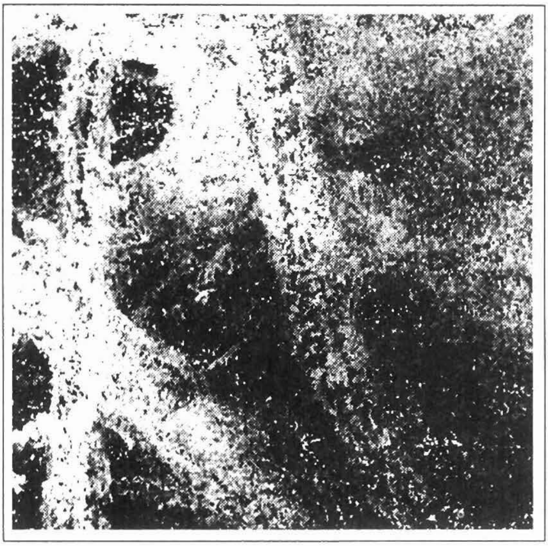

Fig. 2: The unprocessed range image

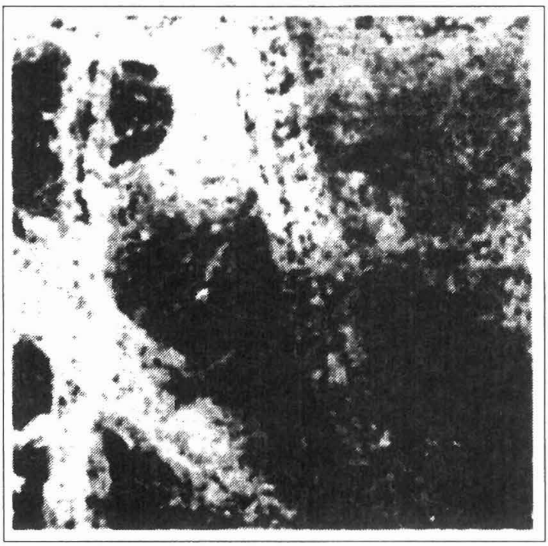

Fig. 3: Heavily averaged range image

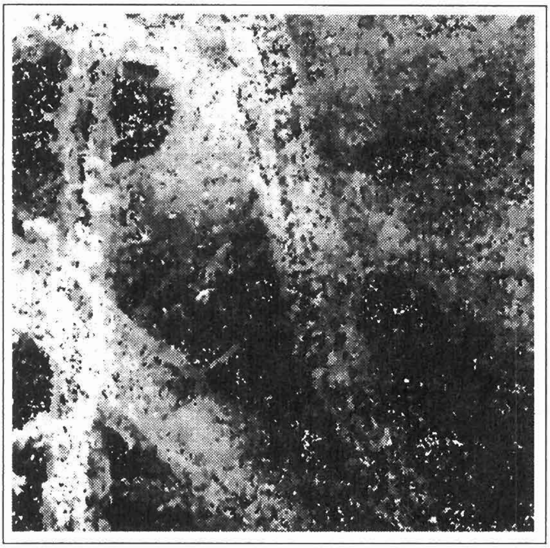

Fig. 4: Result from median filter

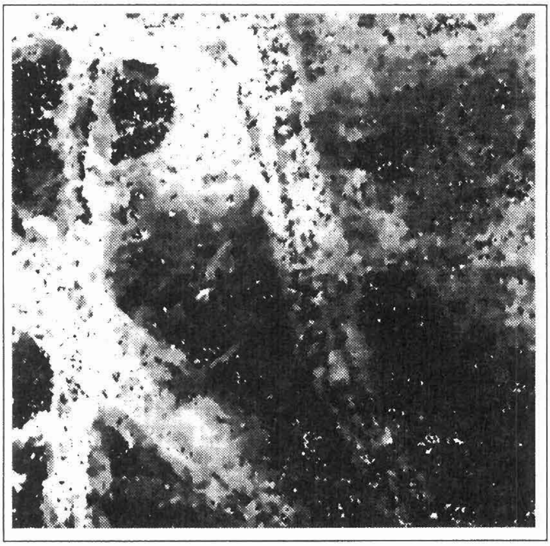

Fig. 5: Result from despeckle filter